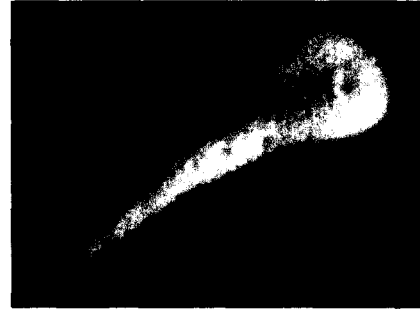


Near-Earth Objects



A radar image of Asteroid 4179 Toutatis taken 12/06/96 shows an elongated object about 4.5 kilometers in extent. Ostro et al. (1999), *Icarus*, 137: pp. 122-139.



Asteroid 433 Eros, 31 km in length, is seen here in a NEAR spacecraft image Veverka et al. (2000), *Science*, 289, pp. 2088-2097.

THE NEAR EARTH OBJECT POPULATION

Near-Earth objects are an important area of study because they are relatively primitive bodies left over from the early solar system formation process, they can be utilized as raw materials for building future structures and habitats within the inner solar system, and their rare, but potentially catastrophic, collisions with Earth make them potential hazards.

A comprehensive search for near-Earth objects (NEOs) not only ensures that there will be no surprises from Earth threatening objects but there will be new discoveries. During future close Earth approaches, these objects can be studied via ground-based programs including radar "imaging" characterizations and Earth orbital satellite observations (e.g., Hubble Space Telescope). In addition, these NEO discoveries will provide future mission targets that are among the most accessible in terms of spacecraft energy requirements. Indeed, many near-Earth asteroids present easier rendezvous and landing opportunities than Earth's own Moon.

While the vast majority of the rocky asteroids reside between the orbits of Mars and Jupiter and almost all the icy comets are resident in the so-called Kuiper belt and Oort cloud in the outer solar system, a significant number of these bodies reside in the Earth's neighborhood. Near-Earth asteroids and near-Earth comets make up the population of so-called near-Earth objects (NEOs). These NEOs are loosely defined as those comets and asteroids that approach the Sun to within 1.3 AU where an astronomical unit is a distance equivalent to the 150 million-kilometers, or 93 million miles between the Earth and Sun. Hence, NEOs can either cross the Earth's orbit or approach it to within distances less than about 45 million kilometers.

A sub-class of these NEOs is the category called potentially hazardous asteroids. These are objects larger than about 150 meters whose orbits approach the Earth's orbit to within 0.05 AU (7.5 million kilometers). Potentially hazardous asteroids are so named because their orbits are close enough to Earth's that gravitational attractions by the planets could, over relatively short time scales, allow them to evolve into Earth crossing orbits – thus allowing the possibility of future collisions.

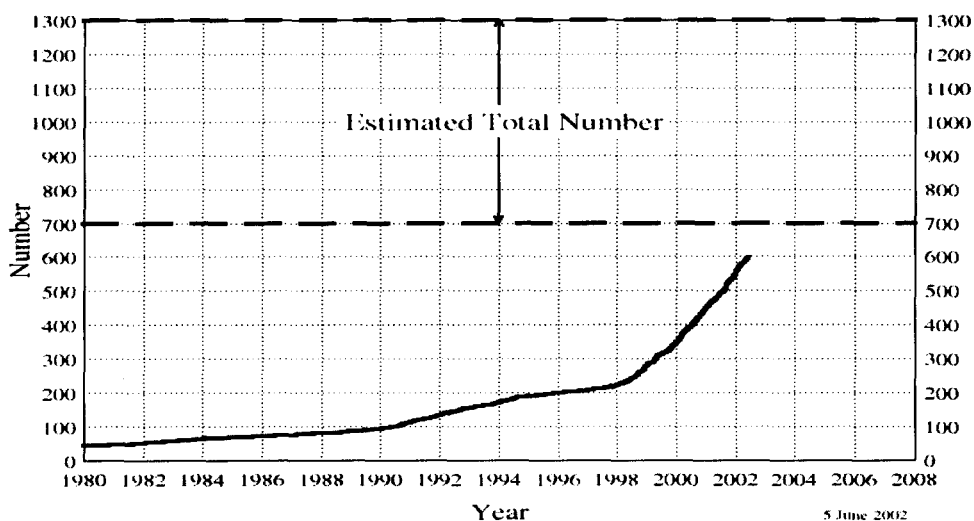
THE THREAT OF NEAR-EARTH OBJECTS TO EARTH

The rate at which asteroids and comets run into Earth strongly depends upon their size. For the very smallest dust and sand-sized particles, more than 25 tons of material hit Earth each day, while for objects large enough to threaten civilization (believed to be 1.5 km and larger), the average time between impacts is measured in hundreds of thousands of years. Although a number of near-Earth comets do exist, they represent only a few percent of the total NEO population. However, because of their greater impact velocities, comets constitute more than a few percent of the hazard.

NASA's NEO DISCOVERY GOAL

NASA's current goal is to discover, within 10 years, at least 90 percent of all NEOs whose diameters are larger than 1 kilometer. The rate with which new objects are discovered will be largest in the first few years because during the latter years of the 10-year interval, more and more detections will be of objects that have been previously found. Currently, the best estimate of the total population of NEOs larger than one kilometer is about 1,000 - a number that has an uncertainty of about 300. The progress toward meeting the NASA goal can be monitored on the NASA NEO Program Office web page (<http://neo.jpl.nasa.gov>) under "Number of NEOs." The following figure presents the progress by mid-2002 toward reaching this goal.

Known Kilometer-Size Near-Earth Asteroids



5 June 2002
Alan B. Chamberlin (JPL)

THE NEO DISCOVERY PROCESS

Not surprisingly, discovery teams that search the largest amount of sky each month have the most success in finding new NEOs. How much sky each telescope covers per month will depend upon a variety of factors including the number of clear nights available for observing, the sensitivity and efficiency of the CCD (light) detector, and the width of the telescope's field-of-view. To increase their discovery efficiency, discovery teams must extend their searches to greater and greater distances from the Earth or, in other words, look for fainter and fainter points of light. Discovering NEOs would mean little were it not for the follow-up observations that refine their initial orbits and ensure that the object's motions and positions will be predictable into the future. Several international follow-up observing sites are operative with many amateur astronomers taking an active and critically important role.

Currently, NASA supports five search teams run by a Principal Investigator (PI). Another discovery site is now underway in Japan.

- Lincoln Near-Earth Asteroid Research (LINEAR). Socorro, NM
Grant Stokes (PI): (<http://www.ll.mit.edu/LINEAR/>)
- Near-Earth Asteroid Tracking (NEAT). Maui, Hawaii and Palomar Mtn., CA
Raymond Bamberg (PI): <http://huey.jpl.nasa.gov/~spravdo/neat.html>
- Spacewatch. Tucson, AZ.
Robert McMillan (PI): <http://pir1www.lpl.arizona.edu/spacewatch/>
- Lowell Observatory Near-Earth Object Search (LONEOS)
Edward Bowell (PI): <http://asteroid.lowell.edu/asteroid/loneos/loneos.html>
- Catalina Sky Survey. Tucson, AZ.
Steven Larson (PI): <http://www.lpl.arizona.edu/css/>
- Japanese Spaceguard Association (JSGA)
Syuzo Isobe (PI): <http://pluto.mtk.nao.ac.jp/SGFJ/index-e.html>

NEAR-EARTH OBJECT ORBIT DETERMINATION AND IMPACT PREDICTION

Once a comet or asteroid is discovered and observers provide follow-up observations, a rough preliminary orbit can be computed. The Minor Planet Center in Cambridge, Massachusetts is the central clearing house for asteroid and cometary observations. This center determines an object's preliminary orbit and then may categorize it as a comet, a near-Earth asteroid or perhaps a potentially hazardous asteroid. When a new NEO is announced, the NEO Program Office at NASA/JPL and the NEODys system in Pisa Italy automatically provide regular orbit and ephemeris updates as more and more observations become available. These updated orbits are then routinely calculated for one hundred years or more into the future to note any possible close Earth approaches. If appropriate, probabilities that this object might strike Earth are then computed and posted on the respective web sites.

THE PHYSICAL CHARACTERIZATION OF NEAR-EARTH OBJECTS

Combining observations from ground-based and space-based NEO programs will provide critically important insights into the composition and structure of near-Earth objects. Optical, infrared and radar observations are all used currently to characterize near-Earth objects. Most meteorites that have struck Earth's surface came from asteroids, so spectral information from well-studied meteorite types is being used to link them with their likely asteroid parent bodies.

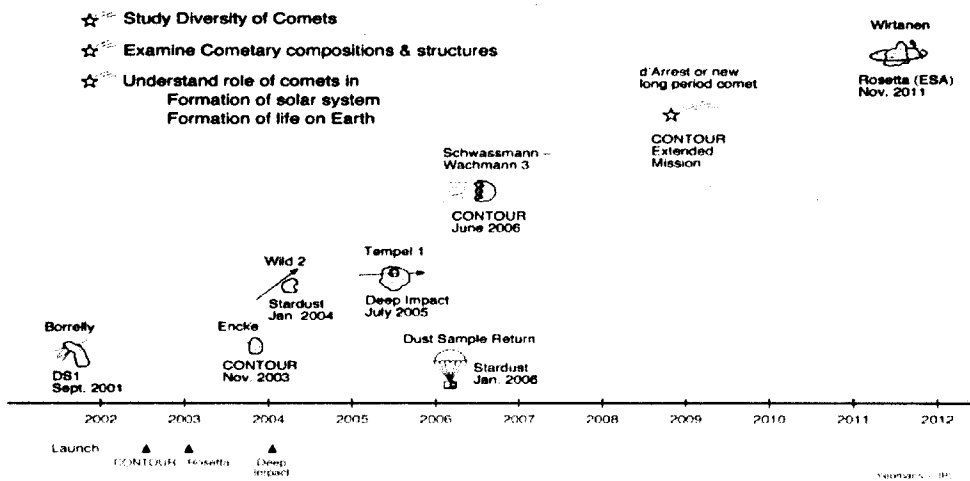
Several space missions designed to make close-up comet and asteroid observations are either completed (NEAR, DS1), in progress (Stardust, CONTOUR) or about to get underway (Deep Impact, Rosetta, MUSES-C). The cartoons on the next page outline the rich set of future missions to comets and asteroids.

THE MITIGATION OF EARTH-THREATENING NEOs

The structures of NEOs probably cover a large spectrum of possibilities, from fragile comets to asteroids that have structures like rubble piles, fractured rock and slabs of solid iron. In the unlikely event that a NEO is found on an Earth-threatening trajectory, knowing its size, shape, mass, composition and structure would be necessary before a successful mitigation campaign could be undertaken. Techniques to deflect NEOs would differ dramatically depending upon the nature of the object. While there has not been a great deal of detailed study into the mitigation of threatening NEOs, it seems clear that the more time available before the predicted impact, the easier the mitigation

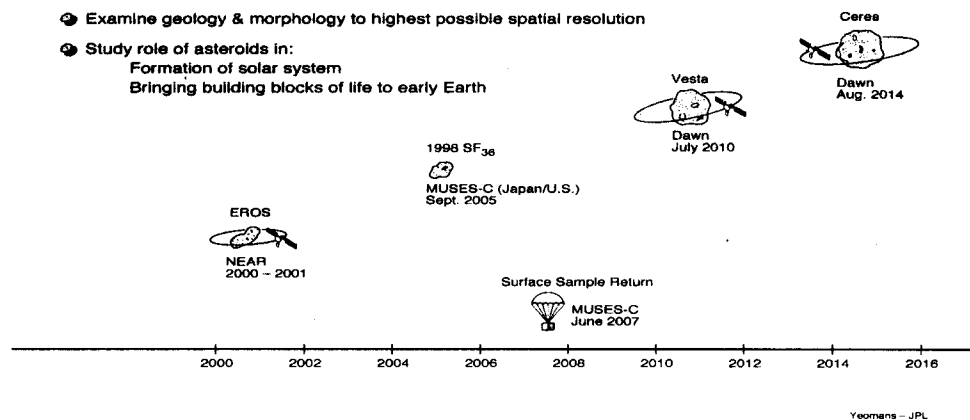
task. Given a few decades of warning time, current technology should be capable of deflecting even the largest NEOs. In general, the most effective deflection technique would cause the threatening NEO to either lose or gain orbital energy. By applying a velocity impulse of sufficient magnitude when the object is nearest the sun, in the direction of the object's motion (or against it), the new trajectory could be altered to miss the Earth entirely. For example, a NEO headed for an Earth impact could be deflected by one Earth radius using a velocity change of less than 2 mm/s if the NEO impulse were applied 40 years in advance. The first and most important step in addressing the NEO problem is to discover the vast majority of the large NEOs and monitor their future motions. These activities are currently underway. Steps should also be taken to increase both the sky coverage for NEO search efforts and to increase the discovery efficiency for NEOs smaller than one kilometer in diameter.

A Decade of Cometary Exploration

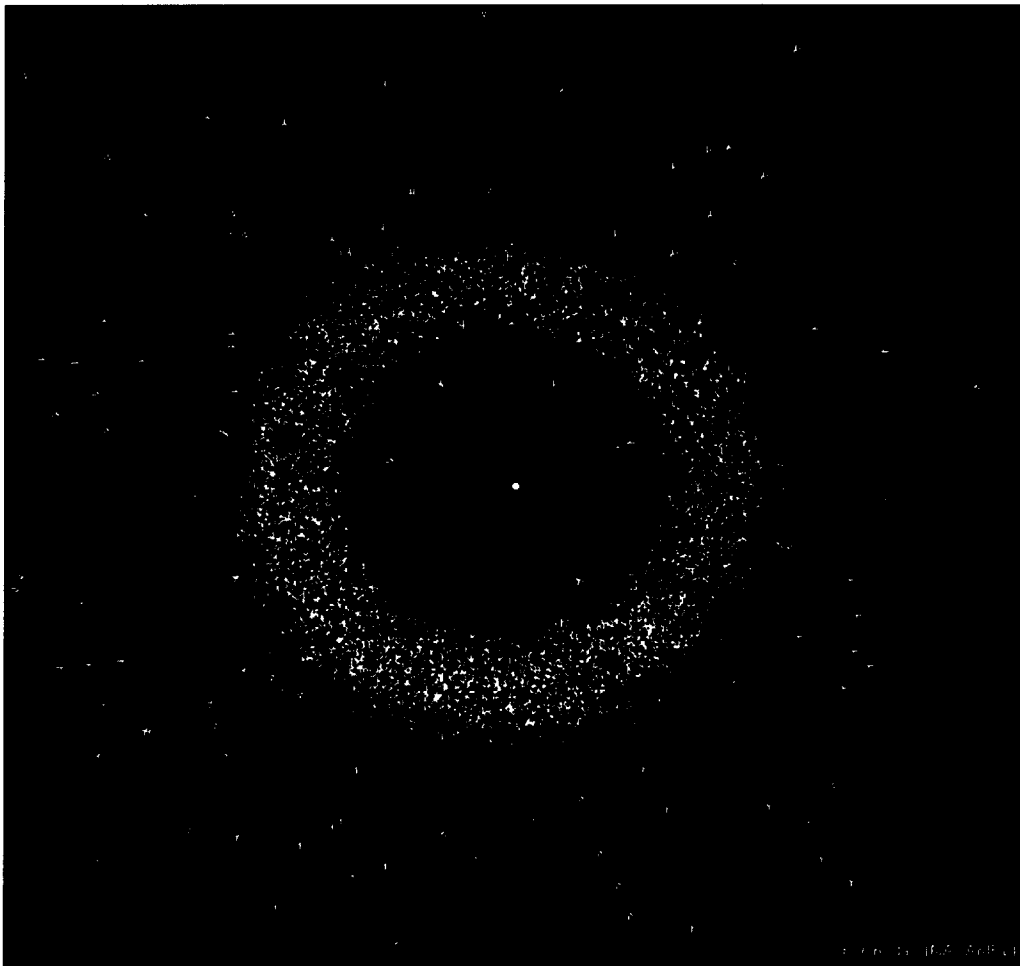


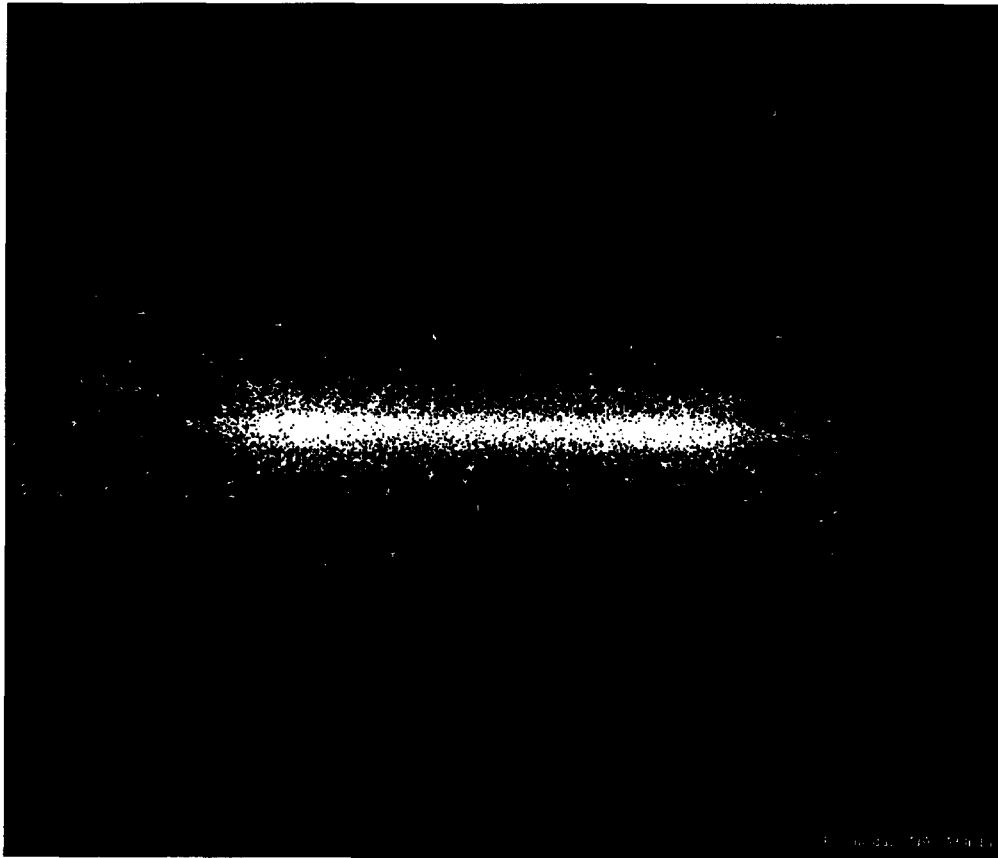
Asteroid Rendezvous Missions

- ④ Study composition of diverse asteroids & identify meteorite parent bodies
- ④ Determine global physical structures of diverse asteroids
- ④ Examine geology & morphology to highest possible spatial resolution
- ④ Study role of asteroids in:
Formation of solar system
Bringing building blocks of life to early Earth



These inner solar system diagrams show the positions of all numbered asteroids and all numbered comets on 2002 July 1. There are a great many more asteroids that are not shown because their orbits are not yet secure enough to warrant a numbering for the asteroid. In the following diagrams, asteroids are yellow dots and comets are symbolized by sunward-pointing wedges. The first diagram shows the view from above the ecliptic plane (the plane containing the Earth's orbit). The second diagram shows the view from the edge of the ecliptic plane. The near-Earth objects are the relatively few asteroids and comets that can travel to within 1.3 AU of the Sun (just inside the orbit of Mars).





For additional information on near-Earth objects, see the following sites and the links therein:

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| http://neo.jpl.nasa.gov | NASA/JPL Near-Earth Object Program Office |
| http://newton.dm.unipi.it/cgi-bin/neodys/neoibo | NEODys (Pisa, Italy) |
| http://pdssbn.astro.umd.edu/ | NASA PDS Small Bodies Node |
| http://earn.dlr.de/ | European Asteroid Research Node |
| http://echo.jpl.nasa.gov/asteroids/ | NASA/JPL Radar Observations Site |
| http://impact.arc.nasa.gov/ | NASA/Ames Comet & Asteroid Impact Hazards |
| http://cfa-www.harvard.edu/cfa/ps/mpc.html | IAU-Minor Planet Center |
| http://www.nearearthobjects.co.uk/ | UK NEO Information Centre |
| http://www.spaceguarduk.com/ | Spaceguard UK |

Produced by D.K. Yeomans (NASA/JPL/Caltech), August, 2002